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TECHNICAL REPORT
ASWEPS REPORT NO. 16

ASWEPS
SHALLOW WATER INVESTIGATION
VIRGINIA CAPES AREA

SEPTEMBER—OCTOBER 1967

FEBRUARY 1969

NAVAL OCEANOGRAPHIC OFFICE
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A B S T R A C T

Thermal structure of a rectangular area approximately 140 kilometers on a side contiguous to the Continental Shelf north-east of Cape Hatteras was investigated between 19 September and 13 October 1968. Major features included an area of warm (>21°C) surface water inshore of the northern wall of the Gulf Stream and a strong sound channel impinging upon the Continental Slope. A subsurface temperature maximum was observed beneath warm surface water at 70 percent of all deepwater stations. Zero layer depths occurred at 56 percent of relatively cold (<19°C) water stations over the Continental Shelf. These features persisted throughout the survey.

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FOREWORD

Oceanic thermal structure prediction for support of Fleet operating units is the prime objective of the Antisubmarine Warfare Environmental Prediction Services (ASWEPS) program. Current prediction techniques which are designed for deepwater areas are not necessarily suitable for the shallow-water areas inshore of the 500-fathom isobath. Since 1967 a series of investigations has been conducted in selected areas to obtain data necessary for modifying deepwater techniques for use in shallow-water areas. This report, the second of a series, describes thermal structure in the Virginia Capes Operating Area during September and October 1967. Subsequent reports will describe thermal structure in the VACAPES Op-Area and in other shallow-water areas.

T. K. Treadwell Jr.

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Captain, U.S. Navy
Commander

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INTRODUCTION

Modification of forecasting techniques developed for deepwater areas as part of the Antisubmarine Warfare Environmental Prediction Services (ASWEPS) program will be required if prediction of near-surface thermal structure is to be extended to the relatively shallow water over the Continental Shelf. A program has been initiated whereby thermal structure will be thoroughly investigated in selected shallow-water areas inshore of the 500-fathom isobath. An area seaward of the Virginia Capes has been selected as an initial test area because of interesting oceanographic features observed there and because of the proximity of Fleet operating areas. Results of the initial survey, conducted in two phases between 24 February and 11 March 1967, have been reported previously (Fisher, 1968). This paper presents the results of the second survey conducted in two phases between 19 September and 13 October 1967.

Phases I and II of this survey were conducted from 19 to 22 September and from 6 to 8 October 1967, respectively. Supplementary data in the area were taken on 8, 12, and 13 October. Station locations during the survey are shown in figures 1 through 3. Bathythermograph and Nansen stations are sequentially designated by numerals and letters, respectively.

DATA COLLECTION

Sea surface temperature (SST) was measured with an airborne radiation thermometer (ART) aboard the ASWEPS aircraft. Two flights were conducted during Phase I and one flight was made during Phase II. The ART data have been corrected for environmental effects in accordance with Pickett (1966). Three overflights of the USNS BENJAMIN F. SANDS (T-AGOR-6) at an altitude of 1,000 feet (318 meters) on 20 September showed a difference of 0.1°C between the ART and the near surface reference temperature (NSRT) system located in the injection intake of the SANDS about 3 meters below the water surface. Navigational accuracy is believed to be within 5 kilometers.

Vertical distribution of temperature and salinity was measured by SANDS using Nansen casts and shipboard expendable bathythermographs (SXBT). Seventy-eight SXBT and 8 Nansen stations were taken during Phase I; 44 SXBT's and 8 Nansen stations were taken during Phase II. During Phase I, SXBT's were dropped at 14.8 kilometer intervals while SANDS steamed a set pattern on each of three consecutive days. The pattern was arranged so that the center station was sampled several times daily. In no case was the western (inshore) sector of the pattern completed, because early morning fog restricted ship's speed. Nansen casts were taken along a track normal to the Continental Shelf between the first and second occupations of the SXBT pattern and were repeated between the second and third occupations. Each section was composed of four casts

with a 14.8-kilometer interval between casts. Upon completion of the third SXBT pattern, three sections were made across an area of warm water with SXBT probes spaced approximately 7.4 kilometers apart. Phase II was modified to obtain two profiles using Nansen casts spaced at intervals of 14.8 kilometers, separated by three sections across the warm water with probes spaced at 7.4-kilometer intervals. The initial Nansen section included five casts, the repeat section included three. Two additional SXBT sections were made during transit to other areas; the first consisting of hourly observations between 36°22'N,74°50'W and 35°59'N,73°50'W and the second consisting of half-hourly observations along 36°56'N between 72°59'W and 75°00'W.

The SXBT probes had a temperature accuracy of ±0.4°C and a depth accuracy of ±4.6 meters or 2 percent (whichever is greater). SST was continuously recorded by the NSRT system. Previous evaluation of the NSRT system showed a mean difference of 0.4°C from the uppermost bottle of a Nansen cast (Fisher, 1967).

Meteorological data recorded every 6 hours and SST data recorded daily by Coast Guard personnel at Chesapeake Light Station (36°58.7'N, 75°42.2'W) are used to describe prevailing weather in the survey area.

DATA ANALYSIS

SST patterns observed during the flights of 20 and 21 September and 6 October are shown in figures 4 through 6. Ship data were not used in the surface analyses because of the differences in time span of the surveys. Corrected ART values were averaged over one-minute periods for plotting, except where strong gradients occurred. Where strong gradients occurred, the actual gradient was plotted. The 20 September analysis is admittedly subjective, because stratus clouds and fog obscured the easternmost leg. This analysis is contoured to best maintain continuity with the pattern of 21 September. Two alternative analyses for 20 September are shown in figure 7. The first shows warm water as an eddy not connected with the Gulf Stream; the second shows warm water as a tongue extending northward from the Gulf Stream rather than from the east as in figure 4.

The major features of the three SST analyses are: (1) a tongue of warm water extending into the survey area from the east, (2) cold water extending into the survey area from the north, (3) a band of warm water along the coast, and (4) location of the Gulf Stream by means of a strong gradient in the southeast corner of the survey area. SST changes of 2°C or greater were observed on 41 overflights of the boundary between the warm water extending into the survey area from the east and the cold water. The mean temperature gradient across the boundary was 0.92°C/km with a minimum of 0.12°C/km and a maximum of 4.70°C/km. Because the flight tracks were not necessarily normal to the boundary, the actual gradients may have been much greater.

Data recorded at the boundary between the warm and cold water in the eastern half of the survey area are complex, and the isotherm patterns shown in the analyses provide only a general configuration of the boundary. Cold-water filaments were observed adjacent to steep temperature gradients on several occasions but lacked sufficient continuity to permit delineation in the analyses. An ART record of the sharp temperature gradient across the boundary between the warm and cold water on 6 October is shown in figure 8. The portion of the flight track shown is indicated in figure 6 by the heavy line AA′. The location of the western boundary between the warm water and the surrounding cooler water is shown in figure 9 for 19, 20, and 21 September and for 6 and 7 October as recorded by the NSRT system aboard the SANDS.

Temperature and salinity sections taken on 6 October are representative of oceanographic conditions throughout the survey. The temperature profile (figure 10) is characterized by (1) a seasonal thermocline which impinges upon the shelf midway between Stations I and J, deepens with increasing water depth until reaching a maximum depth of 55 meters between Stations K and L, and finally shoals to 32 meters at the seaward terminus of the section; (2) a warm core ($T>23°C$) in the near-surface layer in the seaward half of the section; (3) a second warm core ($T>17°C$) centered at a depth of 85 meters at Station M; (4) a cold intrusion ($T<11°C$) between the near-surface warm core and the warm core at 85 meters; and (5) a wedge of cold water ($T<13°C$) adjacent to the slope at a depth of 95 meters. The horizontal temperature gradient between the cold wedge adjacent to the slope and the warm core at 85 meters was 0.27°C/km. Although current measurements were not made, density distribution implies anticyclonic circulation.

The salinity profile for 6 October (figure 10) is similar to the temperature profile in that (1) a core of relatively saline water ($S>35.5°/oo$) coincided with the near-surface warm core, (2) a second core ($S>36.2°/oo$) coincided with the warm core at 85 meters, (3) a wedge of relatively low salinity water ($S<33.5°/oo$) coincided with the cold intrusion at Station M, and (4) a horizontal salinity gradient coincided with the horizontal temperature gradient. An isohaline surface layer was observed only over the shelf.

A composite T-S envelope (figure 11) was constructed using the data from all 16 Nansen casts. Point A is the mean T-S relationship at the surface at Chesapeake Light Station as computed from data for 1956 to 1964 (U.S. Department of Interior, 1957-1967). Point B represents the mean T-S relationship of shelf water as defined by Ford and Miller (1952). Point C represents Gulf Stream water using both observed data and the criterion of Ford and Miller ($T>25°C$, $S=36.0°/oo$). Line DE indicates North Atlantic Central Water as defined by Sverdrup (1946). The distribution of data points generally falls within three different oceanic regimes: (1) a regime where temperature is inversely proportional to salinity as indicated by the line AB, (2) a regime characterized by temperature directly proportional to salinity as indicated by the line DE, and (3) a transitional area between the above two regimes. The three regimes will hereafter

be referred to as shelf water (along AB), slope water (along DE), and intermediate water. No pure Gulf Stream water was sampled.

Schematic diagrams were constructed from SXBT profiles through the warm water in order to delineate features of interest to the study in the simplest possible manner. The three sections of 21 and 22 September (figure 12) are characterized by (1) the absence of a mixed layer over the shelf, (2) warm cores ($T > 23°C$) in the near-surface layer, (3) a cold wedge ($T < 10°C$) adjacent to the Continental Slope, (4) multiple temperature inversions near the bottom of the seasonal thermocline, and (5) an isothermal bubble (14.1°C) at the seaward end of the northernmost profile.

The three sections were repeated on 7 October (figure 13) and are characterized by (1) a mixed surface layer at all stations, (2) warm cores ($T > 20°C$) in the near-surface layer, (3) the absence of cold water ($T < 10°C$) against the shallow portions of the slope, (4) temperature inversions near the bottom of the seasonal thermocline, and (5) an isothermal bubble (14.1°C) at the seaward end of the southernmost profile.

Comparison between the two sets of profiles is difficult, because the small dimensions and complexity of the above features make delineation difficult although station spacing was only 7.4 kilometers. In general, (1) the thickness of the mixed layer was greater in deepwater than it was over the shelf, (2) the warm core cooled from greater than 23°C to about 20°C, and (3) the cold wedge disappeared from all but the southernmost section in October.

The near-surface thermal structure in the warm water ($\geq 21°C$) differed from that of the surrounding cold water ($\leq 19°C$) in two respects. First, a subsurface temperature maximum was observed at 70 percent of the warm-water stations as compared to a maximum in only 17 percent of the cold-water stations. Secondly, zero layer depth was observed at only 10 percent of the warm-water stations as compared to zero layers in 58 percent of the cold-water stations. Occurrences of subsurface temperature maximum and zero layer depth in the boundary between the warm and cold water were 37 and 31 percent, respectively. Approximately 86 percent of warm-water stations and 14 percent of cold-water stations were made in water deeper than 500 meters, while 8 percent of the warm-water stations and 83 percent of the cold-water stations were made in water shallower than 150 meters.

The relationship between thermal structure and water depth for each water regime is given in table 1. The relatively high percentages of (1) warm water with a subsurface temperature maximum in deep water and (2) cold water with zero layer depth in shallow water are of particular interest.

Two additional schematic diagrams are included to provide further details of features described above. A section made on 7 and 8 October between 36°29'N,75°04'W and 35°54'N,73°33'W (figure 14) shows that the

isothermal bubble occupies an area approximately 65 kilometers long between the slope and the northern edge of the Gulf Stream. Maximum thickness of the bubble was approximately 155 meters. Also of interest is the increase in layer depth from less than 32 meters inshore of the northern edge of the Gulf Stream to about 65 meters within the Gulf Stream.

Table 1
Variability of Near-Surface Thermal Structure
(percent)

	No.	Subsurface Temp. Max.		Zero Layer Depth		
	Obs.	Shallow*	Deep*	Shallow	Deep	Other**
warm (≥ 21°C)	40	0	70	5	5	20
boundary (19° to 21°C)	41	5	37	32	0	26
cool (≤ 19°C)	38	10	7	56	0	27

*Shallow: water depth less than 150m
Deep: water depth greater than 500m
**Includes all other thermal structures, regardless of depth

A profile on 12 and 13 October along 36°56'N between 73°W and 75°W (figure 15) delineates the cold wedge adjacent to the slope and the associated temperature inversion to the east. The structure of these features is less complex than that of the sections taken in the warm water to the south. The widths of the cold wedge and the interval between the wedge and the cold parcel to the east are about 24 and 20 kilometers, respectively. The inversion was tracked for approximately 92 kilometers without reaching the eastern boundary. Near-surface water less than 10°C was observed only in the wedge. Layer depth in deepwater (mean 28 meters) was slightly deeper than over the shelf (mean 23 meters).

Weather observations recorded every 6 hours at Chesapeake Light Station are shown in figure 16 for 1800Z 17 September to 2400Z 13 October. Portions of the record corresponding to Phases I and II are indicated along the time scale. Phase I was characterized by variation in the air temperature from a low of 19.5°C to a high of 23.0°C, little or no wind, and moderate cloud cover. Phase II was characterized by variation in air temperature from a low of 17.5°C to a high of 21.5°C, relatively high winds, and predominantly overcast skies. Frontal passages are indicated by increase in both wind speed and cloud cover. Evacuation of the light station from early 16 September to late 17 September precluded weather observations during Hurricane Doria.

Heat budget computations were made by the James (1966) method for the 5 days that SANDS remained in the area of the warm water. Table 2 gives the computed values for each of the factors involved in heat exchange across the air-sea interface in the warm water and in the surrounding cold water. Each water type was assigned a representative SST for compar-

ative purposes. As would be expected, heating was maximum under clear skies and low winds; minimum heating occurred with overcast skies and high winds. Heat gained in the cold water was approximately 200 gram-calories per square centimeter per day greater than heat gained in the warm water. Evaporation and sensible heat loss accounted for most of the difference in heating.

Table 2
Heat Exchange Across the Air-Sea Interface
in the Area of the Warm Water
(in gm-cal/cm^2/day)

Date	Water Mass	SST	Q_{s-r}	Q_b	$Q_{e/c}$	Q_h	ΣQ	Diff.
19 Sept.	Warm	24°C	+350	-104	-195	-70	-19	
	Cold	19°C	+350	-98	-37	-11	+204	223
20 Sept.	Warm	24°	+434	-122	-64	-16	+232	
	Cold	19°	+434	-113	+9	+9	+339	107
21 Sept.	Warm	24°	+408	-128	-174	-33	+73	
	Cold	19°	+408	-117	+25	+29	+345	272
7 Oct.	Warm	22°	+150	-88	-479	-139	-556	
	Cold	20°	+150	-85	+283	-61	-279	277
8 Oct.	Warm	22°	+370	-93	-147	-28	-102	
	Cold	20°	+370	-81	-14	+35	+310	208

Q_{s-r}: Effective insolation
Q_b: Effective back radiation
$Q_{e/c}$: Latent heat of evaporation (-) or condensation (+)
Q_h: Sensible heat transfer
Q: $Q_{s-r} + Q_b + Q_{e/c} + Q_h$

Ray path diagrams were constructed from station data representative of each water mass (figure 17). The sound projector was assumed to be at a depth of 5 meters in both diagrams, with a second projector at a depth of 45 meters in the warm water. A limiting ray occurs at 6 degrees in the warm water; that is, energy projected at angles less than 6 degrees below the horizon is refracted toward the surface where it is trapped in the surface duct, and energy projected at angles greater than 6 degrees below the horizon is refracted toward the bottom. A shadow zone occurs between the surface duct and the lower half of the limiting ray. Energy projected along the sound channel axis between the angles of +12.9 and -10.7 degrees is trapped in the channel thereby illuminating much of the shadow zone. The sound field in the cold water is greatly simplified with all projected energy refracted toward the bottom.

DISCUSSION

The most interesting feature in the analyses is the presence of warm water in the eastern segment of the survey area. The thermal structure in the boundary between the warm water and the surrounding cooler water is similar to that of the northern edge of the Gulf Stream but less intense. Minimum observed SST occurred in a filament at the cold-water side of the boundary. Maximum observed salinity in the warm water (36.2°/oo) compared with salinity values associated with the Gulf Stream (> 36.0°/oo). Because only two observations exceeded 34.7°/oo, the warm water must be classified as intermediate water rather than Gulf Stream water. Temperature sections show no direct influence of the warm water below 60 meters. However, the configuration of underlying temperature inversions in the area of the warm water is considerably more complex than the configuration of the inversion at 37°N, suggesting that the influence of the warm water extends through the seasonal thermocline.

The area of warm water corresponds to warm water observed by Ichiye (1966, 1967) approximately 150 kilometers northeast of Cape Hatteras. A small cold core in the center of this eddy is believed to be caused by entrainment of cold surface water from the northeast. A similar process would account for the cold tongue extending northeastward to the south of the warm water observed by SANDS.

A transient zone of intermediate SST was reported between the coastal water and the Gulf Stream (Mazeika, 1968). This intermediate zone is characterized by (1) an initial temperature change of approximately 8°C in less than 2 kilometers, (2) an area of varied SST as much as 111 kilometers in width, and (3) a second, steeper temperature gradient at the northern edge of the Gulf Stream. The zone was observed to vary in width during a 24-hour period from being almost nonexistent to 28 kilometers. Alternating cold-water belts and warm cores were observed within the zone. Similarity between Mazeika's data and features observed by Ichiye and the present survey suggests that Mazeika may have also traversed the warm eddy. Warm water observed during a survey seaward of the Virginia Capes in February and March 1967 suggests that intrusion of warm water into coastal areas occurs throughout the year. The mean temperature gradient across the boundary (0.9°C/km) observed during the present survey compares favorably with the gradient of 0.8°C/km observed during the winter survey.

Little displacement of the western boundary of the warm water was observed during Phase I. During the interval between phases, however, both counterclockwise rotation of the boundary and dissipation of the warm core were observed. With the exception of a 3-day period between 30 September and 3 October when northerly winds occurred, wind-drift currents were toward the east. It is unlikely that the northerly winds could have overcome momentum imparted by the Gulf Stream to the extent observed. A decrease in SST of nearly 2.5°C was observed in the gyre between the flight of 21 September and the flight of 6 October, whereas little or

no changes were observed in the SST of the surrounding cold water. Differential heating across the air-sea interface, as discussed previously, and mixing between the two water masses could simultaneously maintain SST in the cold water while causing a decrease of SST in the warm water. Complete dissipation or movement out of the survey area of one system and replacement by a second may also have occurred during the interval between phases.

Origin of the warm water in the Gulf Stream is likely. An orderly progression which might be associated with a warm-water gyre would include (1) formation of a meander in the northern edge of the Gulf Stream upstream from Cape Hatteras by processes as yet unknown, (2) intrusion of the meander as a tongue into coastal water north of Cape Hatteras, (3) deformation of the tongue from shear between the coastal current and the Gulf Stream, (4) severance of the tongue from the Gulf Stream by excessive shear and formation of an eddy as described by Ichiye, and (5) eventual dissipation through mixing and heat loss to the atmosphere unless replenished by a later intrusion. Energy supplied by the Gulf Stream would probably impart northerly movement to the gyre. Data are presently insufficient to support the above supposition.

Temperature inversions observed at the base of the seasonal thermocline are probably a cold wedge and offshore bubble described by Cresswell (1967). According to Cresswell, the steps in the formation of the wedge and the offshore bubble are (1) formation of cold bottom shelf water over the shelf during winter months; (2) projection over the slope with size of the resulting wedge determined by the amount of shelf water formed; (3) elimination of the excess water through mixing processes (calving), probably by tidal agitation and shoaling of internal waves; and (4) introduction of parcels of the eliminated water into the intermediate water, thus forming the offshore bubble. Absence of the wedge at two of the three sections repeated during Phase II and reduction in wedge size in the third section suggest that the wedge is in the final stages of its annual cycle. The wedge at 37°N is probably more representative of wedge structure along most of the shelf than the wedge farther to the south. The latter wedge appears to have been deformed by currents associated with the warm gyre. The three deepest Nansen bottles at Station C (35, 40, and 45 meters) and a single bottle at Station M (48 meters) appear to be in the wedge and are shown in the composite T-S envelope (figure 11) as points with temperature less than 13.5°C and a salinity range between 32.4 and 33.4°/oo. This water, having formed during the previous winter, should be called <u>old shelf water</u> to differentiate it from water modified during summer. Temperatures in the offshore bubble are generally greater than those in the wedge and cannot be distinguished from shelf water on the T-S envelope.

Formation of an isothermal surface layer with corresponding deepening in layer depth as observed during the interval between phases is in agreement with Bigelow's (1933) description of autumnal processes over the shelf. No evidence of bottom warming caused by intrusion of oceanic

water along the shelf as described by Bigelow was noted. This is in opposition to the February-March survey when bottom warming, probably due to wind-induced upwelling, was observed. Southerly winds observed during the present survey were of the same magnitude and duration as winds during the winter survey. However, the strong thermal stratification observed during the present survey would require stronger winds to induce upwelling than are required in winter, when little stratification occurs.

The sound transmission characteristics in the two water regimes studied are considerably different, as shown in figure 17. A relatively large change in submarine detection would occur within a few minutes while transiting between the two regimes. This illustrates the need for improvement of prediction techniques and an increase in oceanographic data. It also illustrates the importance of considerable data collection and interpretation by fleet units operating within any given area.

Development of analysis and prediction techniques suitable for such areas as considered in this study require a reasonable input of synoptic oceanographic data and a knowledge of environmental processes both within the area and in adjacent areas. During the present survey, three external processes were observed to affect the local regime: (1) intrusion of warm, saline water from the Gulf Stream, (2) advection of cold shelf water by the coastal current, and (3) energy exchange across the air-sea interface. A fourth external process, accumulation of cold runoff over the shelf, continued to affect the local area.

A process whereby Gulf Stream water would intrude into coastal water was discussed previously. A relatively dense network of synoptic oceanographic observations over short periods between Cape Fear and the Virginia Capes is required to verify this postulation. Upon determination of the life cycle of the warm intrusion, regular observation would be required to detect newly formed systems. Once detected, the system may be tracked and predicted by means of a moderate increase of sea surface temperature (CTEM) reports and bathythermograph (BATHY) reports.

The amount of shelf water advected into the survey area by southwesterly flowing coastal currents could be predicted if (1) CTEM and BATHY reports are sufficient to define the temperature field and (2) computed wind drift currents and estimated geostrophic currents are sufficient to define the current field. However, the assumption that shelf water is present unless replaced by an intrusion of denser oceanic water would eliminate the need for current data. In inshore areas, however, the surface layer may be greatly modified by low-density effluent from rivers and estuaries.

The cold wedge and an associated offshore bubble are apparently seasonal phenomena. Formation of the wedge is probably a function of the severity of the previous winter and of the amount of precipitation received on the eastern seaboard; dissipation is a function of dynamic oceanographic processes (intrusion of oceanic water, energy exchange across the air-sea interface, shoaling of internal waves, and tidal agitation) encountered during the ensuing summer. The complexity of each factor involved in the wedge life cycle makes long-term prediction unrealistic. Short-term prediction, on the order of two or three weeks, is probably possible through monitoring SXBT sections taken normal to the shelf at regular intervals.

Estimation of energy exchange across the air-sea interface in this area is presently possible. Data from Chesapeake Light Station should suffice as meteorological input over the entire area, but oceanographic data representative of each water mass would be required. Mixing and advection in this area and season are expected to be more important in heat budget computations than heat exchange across the air-sea interface. Wind-induced mixing would be expected to have less effect over the stratified shelf water than in the warm gyre, where a mixed layer occurred.

Prediction of subsurface thermal structure by means of SST observations is desirable but not completely reliable. Generalities concerning the subsurface water structure can be used to supplement existing data provided that (1) the characteristics of a given water regime are known and (2) the water regime can be identified from surface observations. The subsurface temperature maximum associated with the warm oceanic water is an example of thermal structure which may be associated with a given water regime. Based on data obtained during the present survey, a subsurface temperature maximum could be expected to occur beneath 70 percent of the warm-water surface observations made over deepwater with the ART aboard the ASWEPS aircraft.

CONCLUSIONS

1. Warm water observed in the eastern segment of the survey area intruded into coastal water from the Gulf Stream. Thermohaline relationships infer considerable modification of this water after separation from the Gulf Stream. The dynamic processes responsible for the intrusion are as yet unknown.

2. The cold wedge observed adjacent to the Continental Shelf and the associated offshore bubble are vestiges of surplus cold shelf water formed during the previous winter.

3. Based on the results of this survey, the probability of a subsurface temperature maximum occurring in areas of warm surface water over

deepwater is 0.70. Likewise, the probability of zero layer depth occurring in areas of cold shallow water is 0.56.

4. Thermal structure prediction over the Continental Shelf adjacent to the Virginia Capes requires (1) additional research into dynamic processes involved in the formation of the warm gyre and the cold wedge detected in this study and (2) an increase of thermohaline data to delineate the limits of these features.

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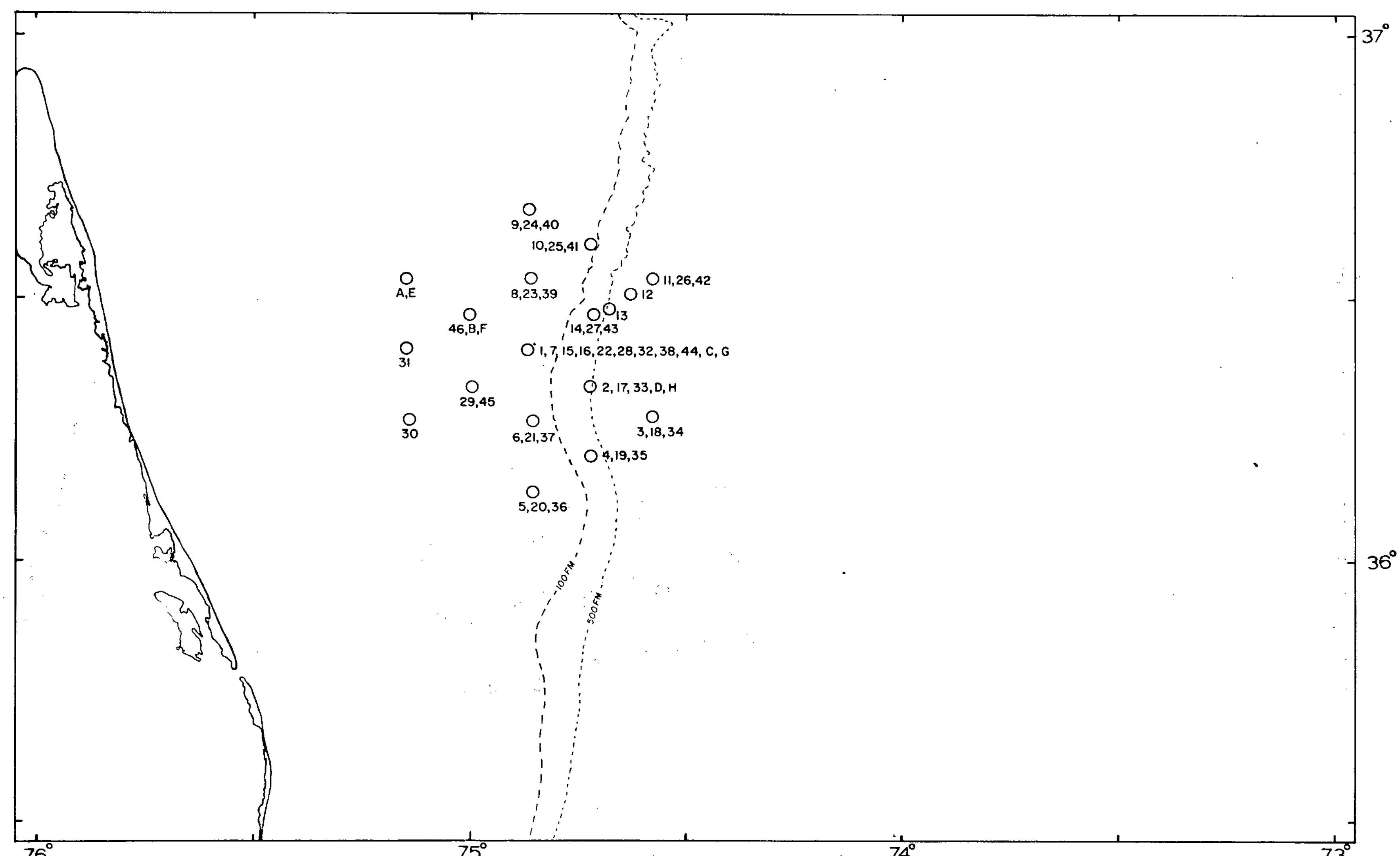

Figure 1 Location of Phase I Stations (0331Z 19 September-1519Z 21 September 1967)

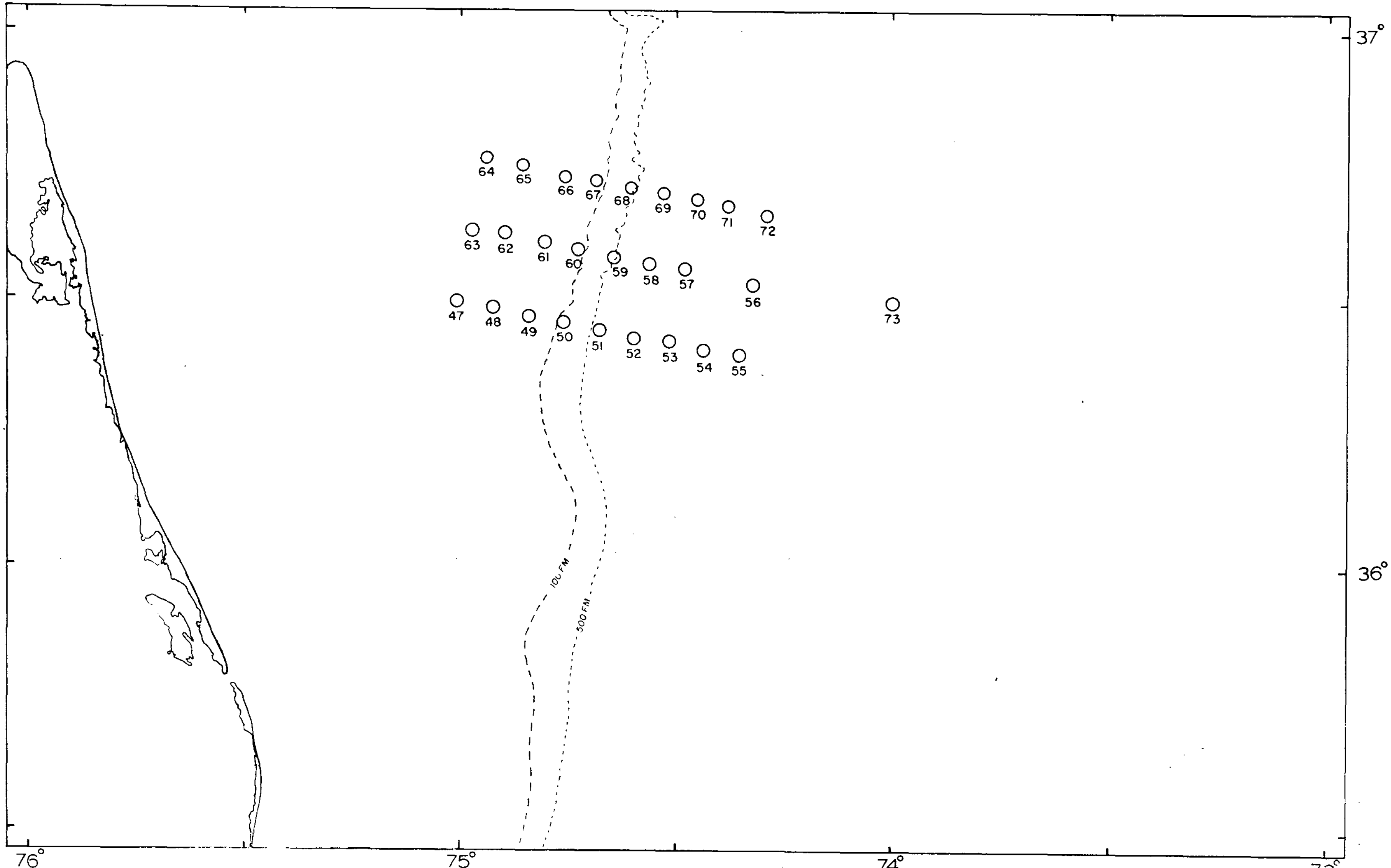

Figure 2 Location of Phase I Stations (1532Z 21 September-0245Z 22 September 1967)

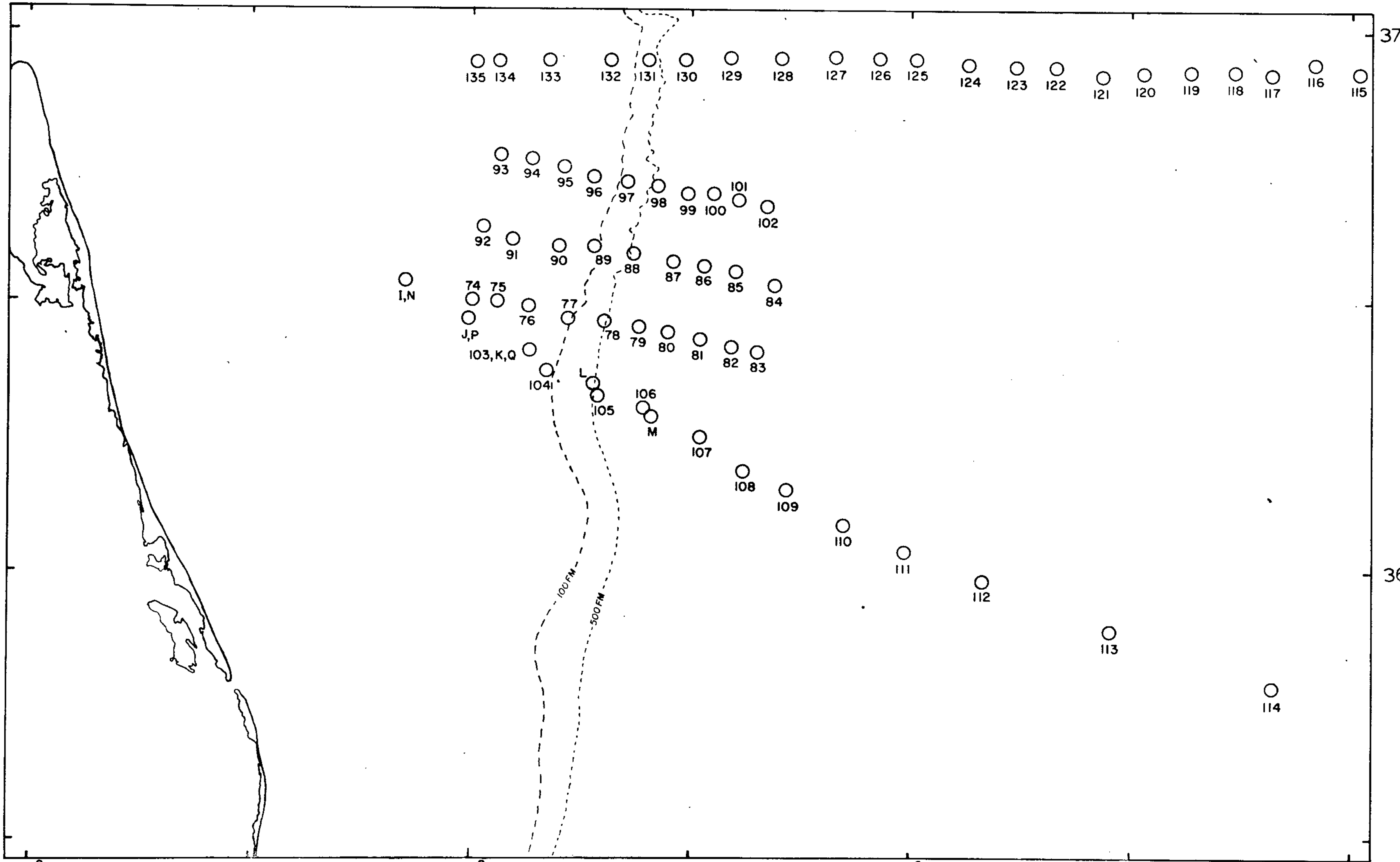

Figure 3 Location of Phase II and In Transit Stations (6-13 October 1967)

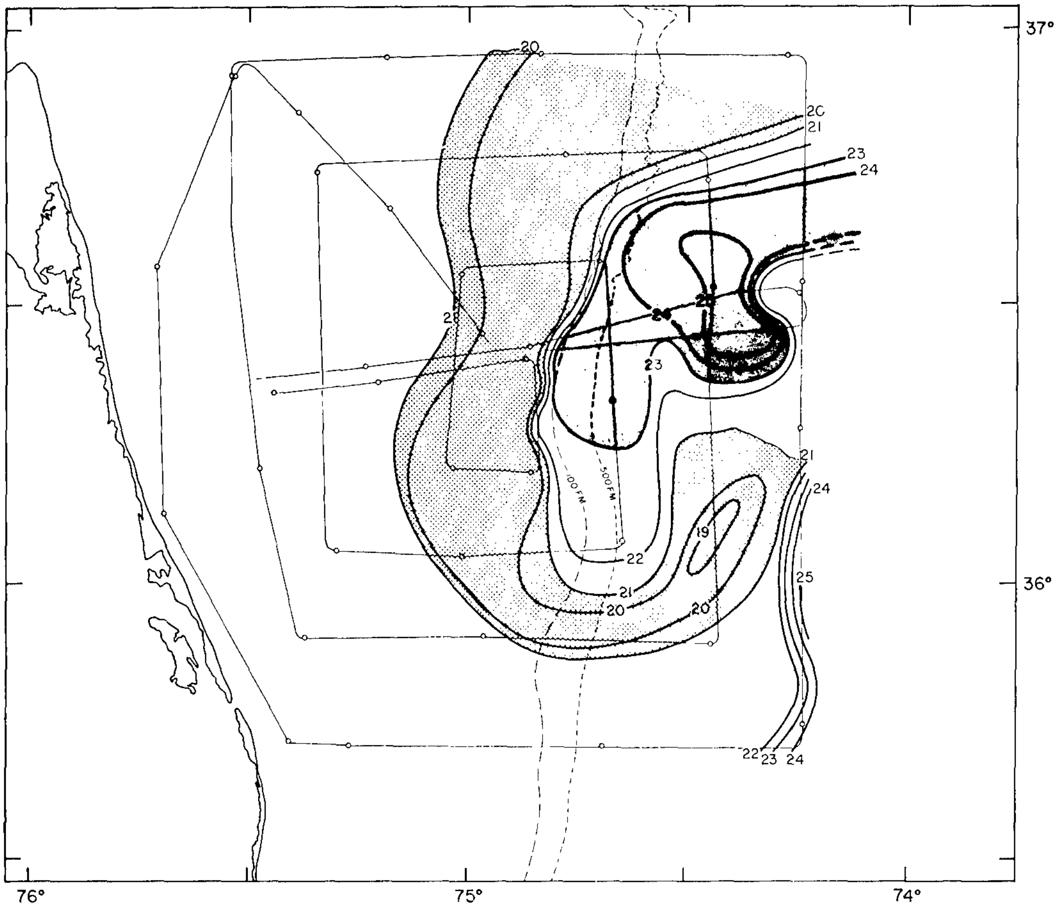

Figure 4 Surface Isotherms 20 September 1967 (°C)

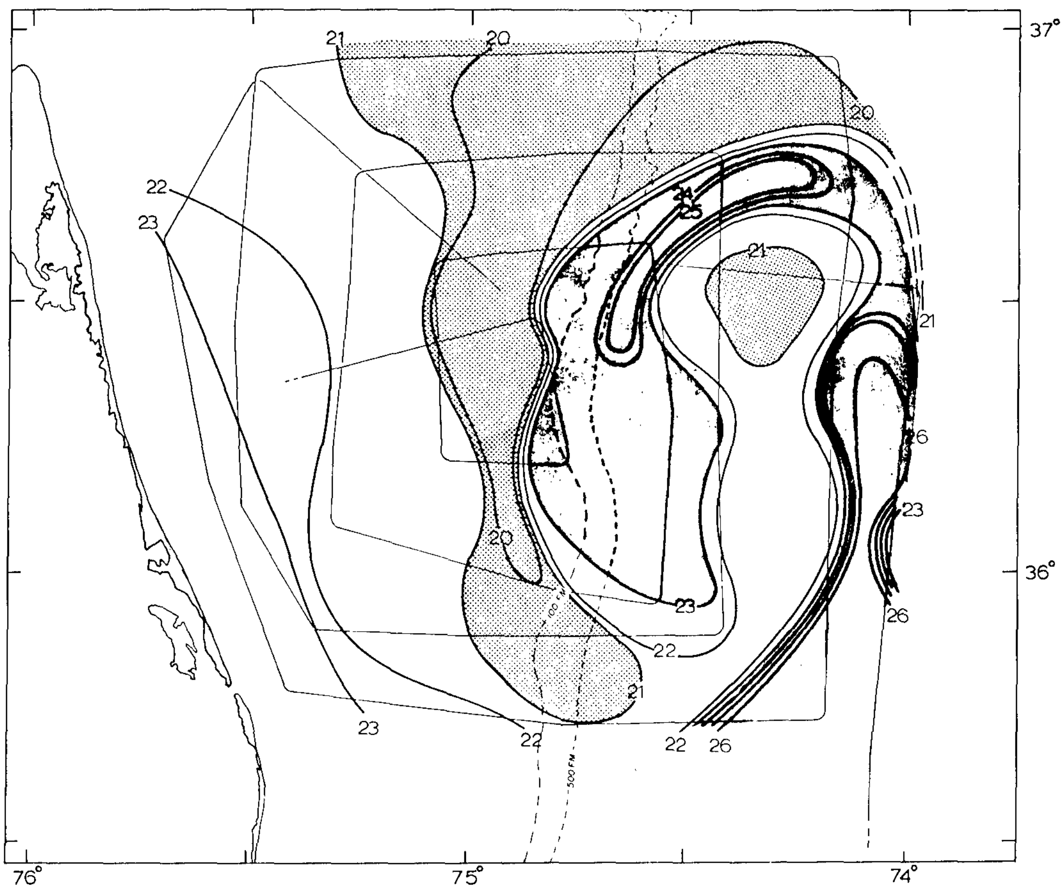

Figure 5 Surface Isotherms 21 September 1967 (°C)

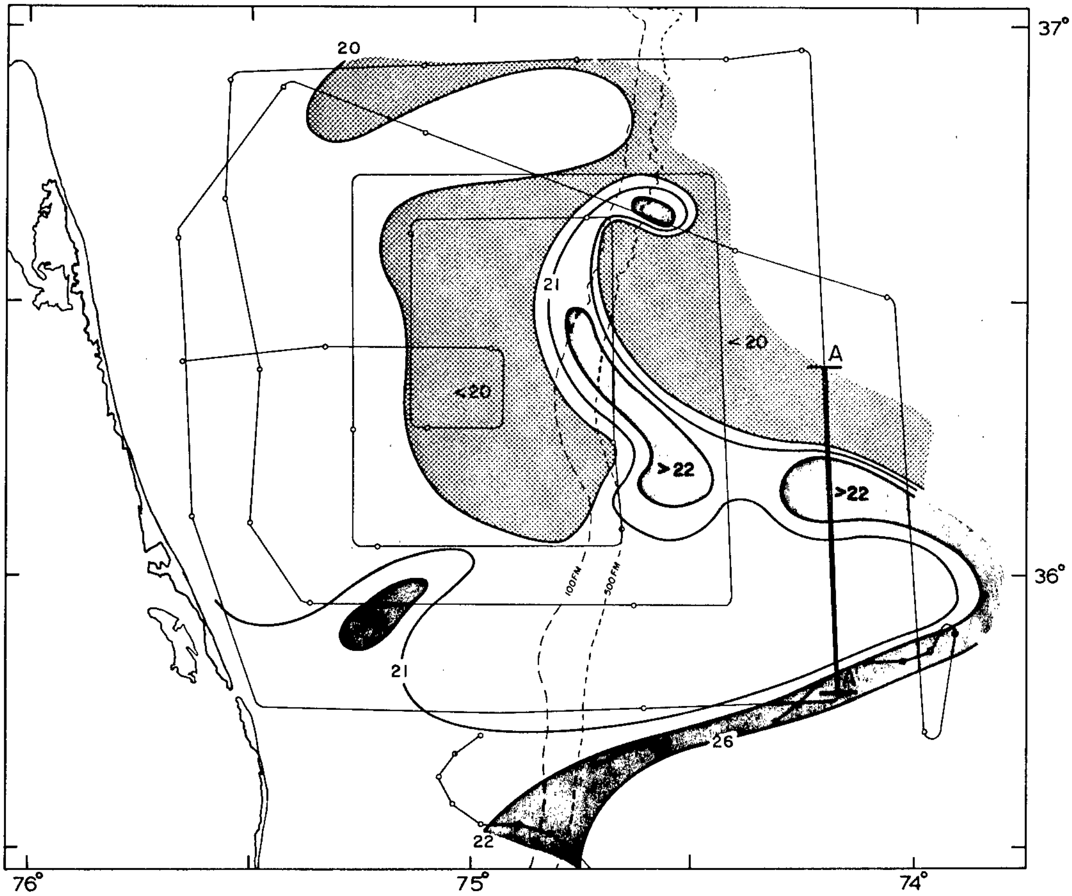

Figure 6 Surface Isotherms 6 October 1967 (°C)

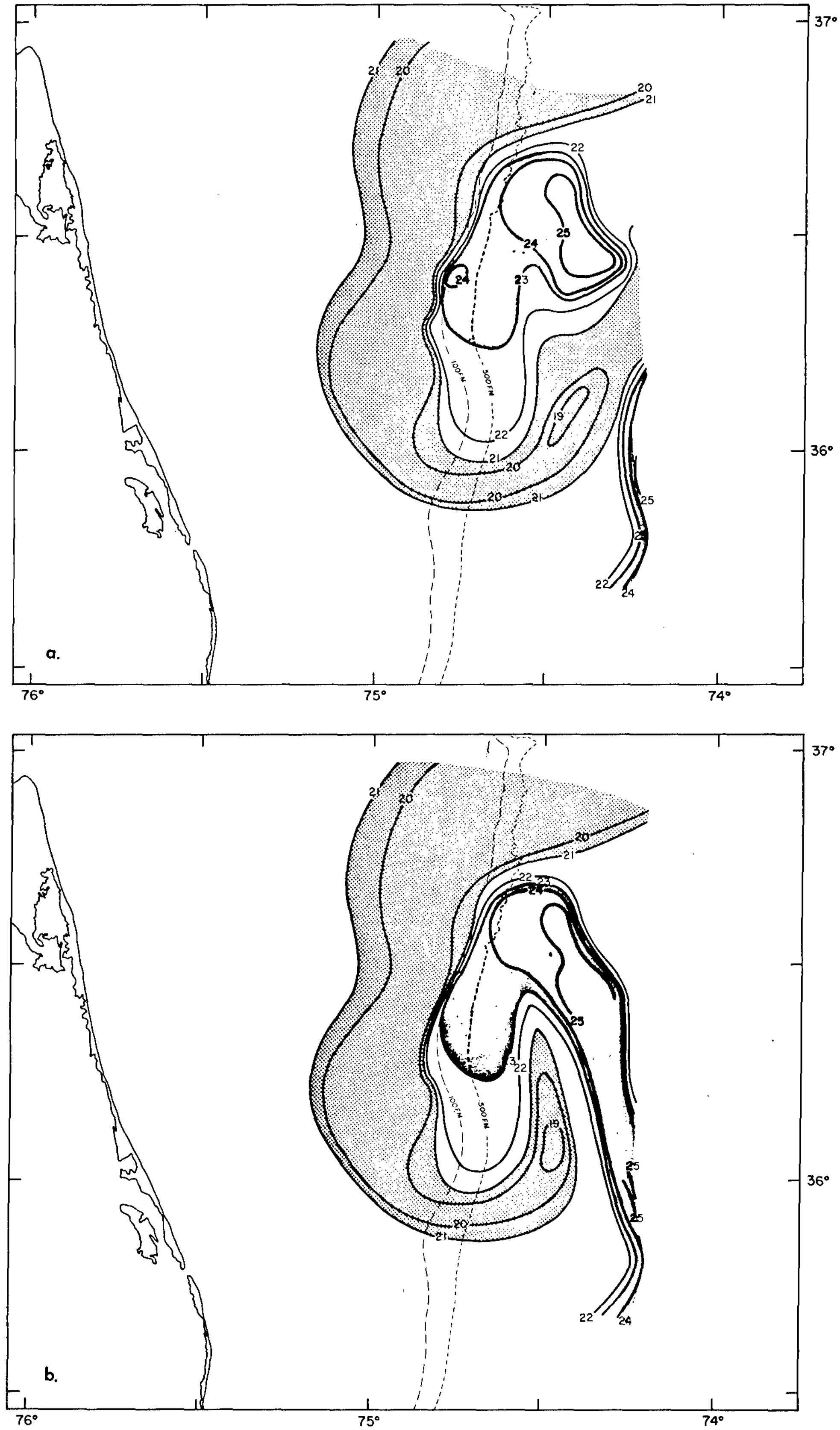

Figure 7 Alternative Analyses 20 September 1967 (°C)

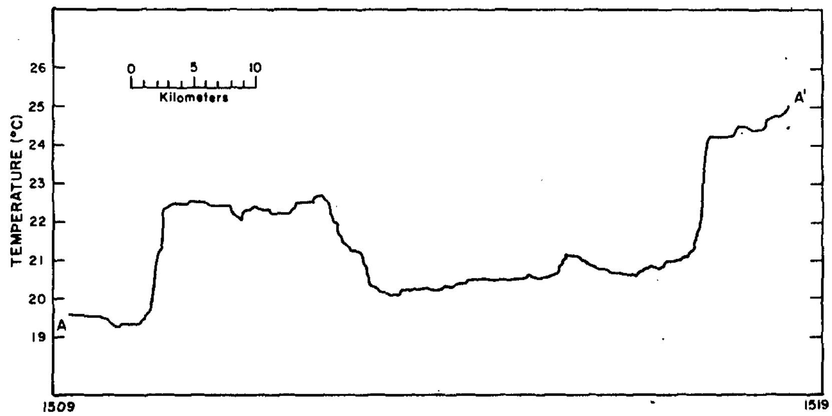

Figure 8 ART Record 6 October 1967

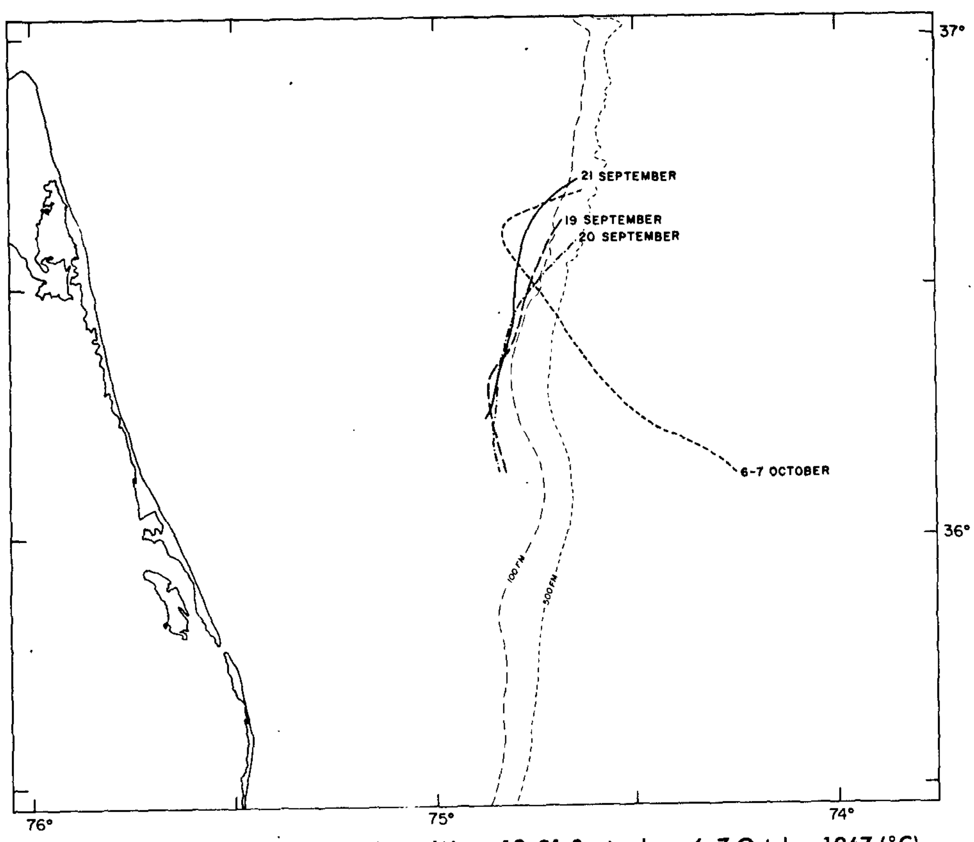

Figure 9 Western Boundary of Warm Water 19-21 September, 6-7 October 1967 (°C)

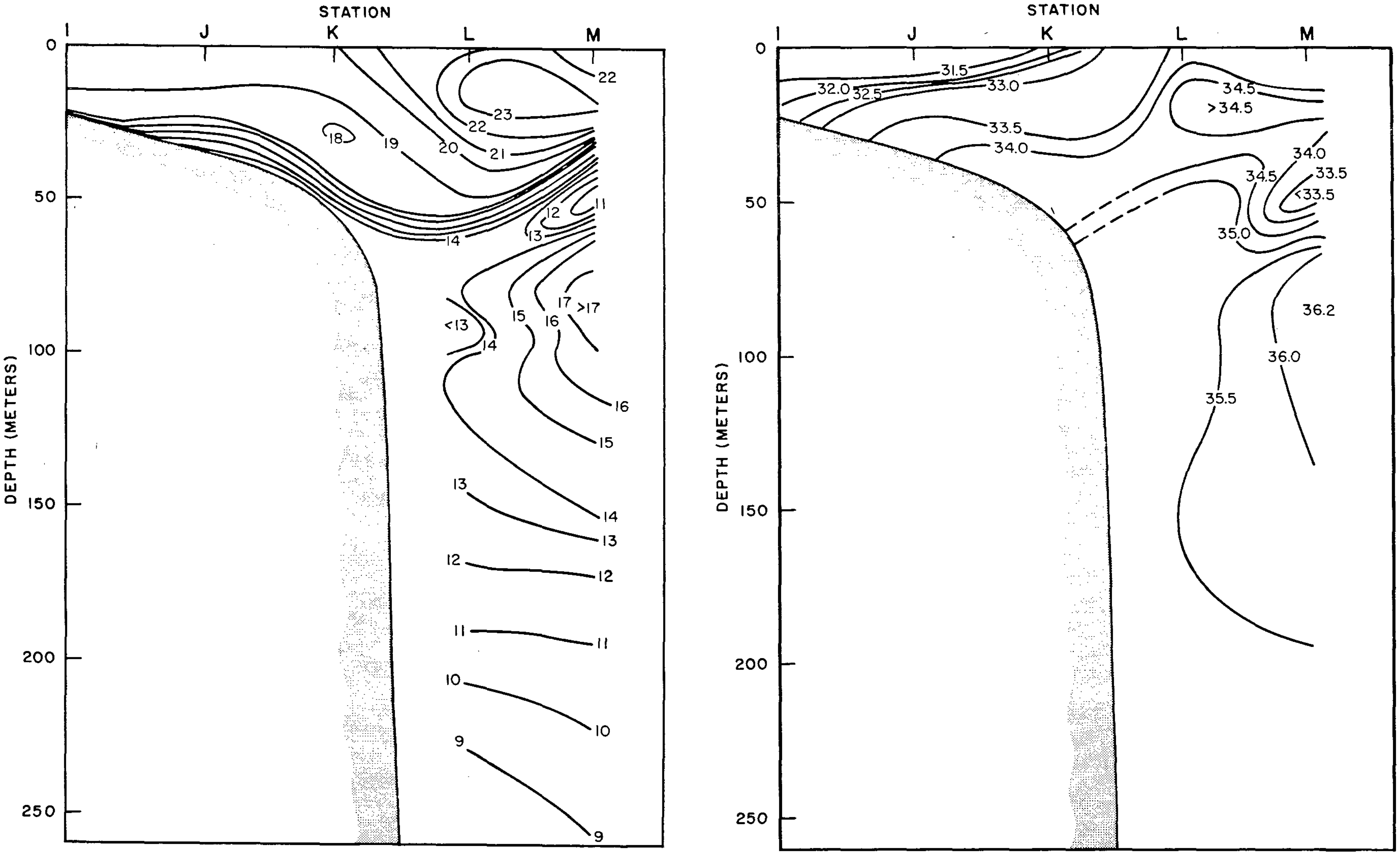

Figure 10 *Temperature (°C) and Salinity (°/oo) Sections 6 October 1967*

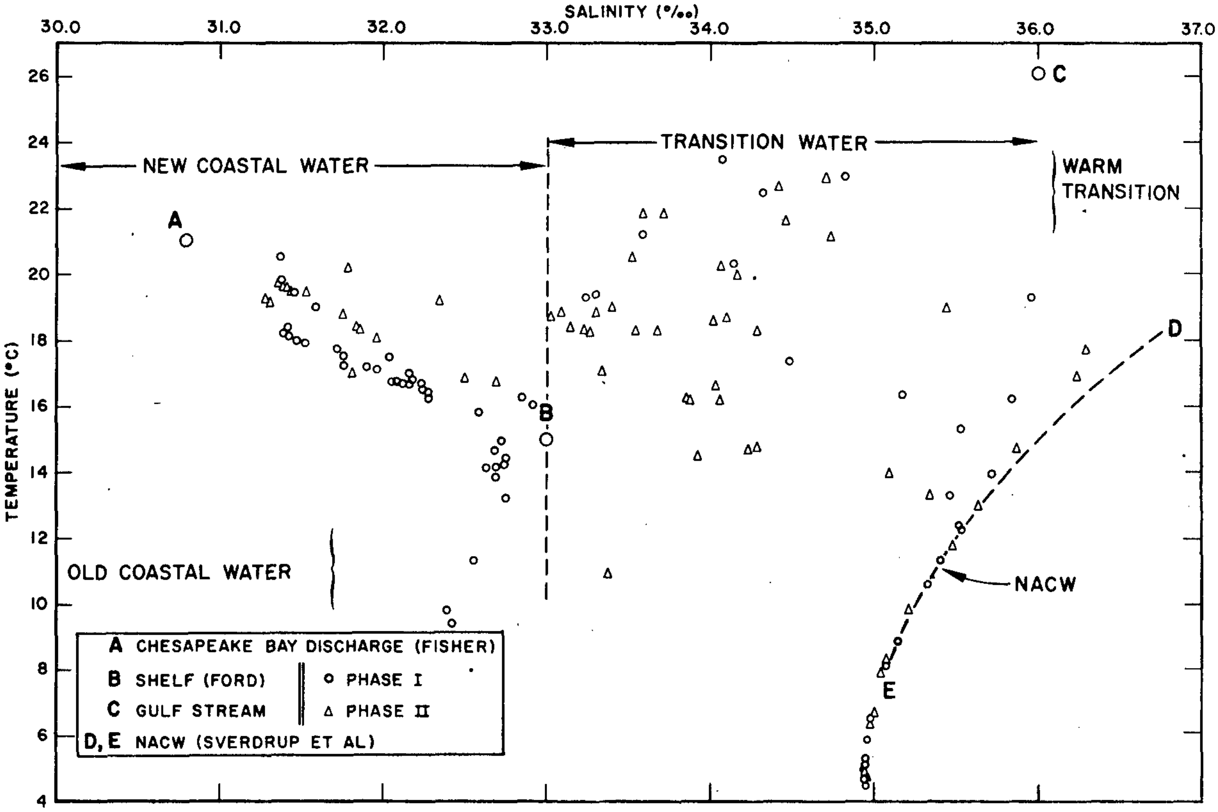

Figure 11 Composite T-S Envelope, Stations A to P

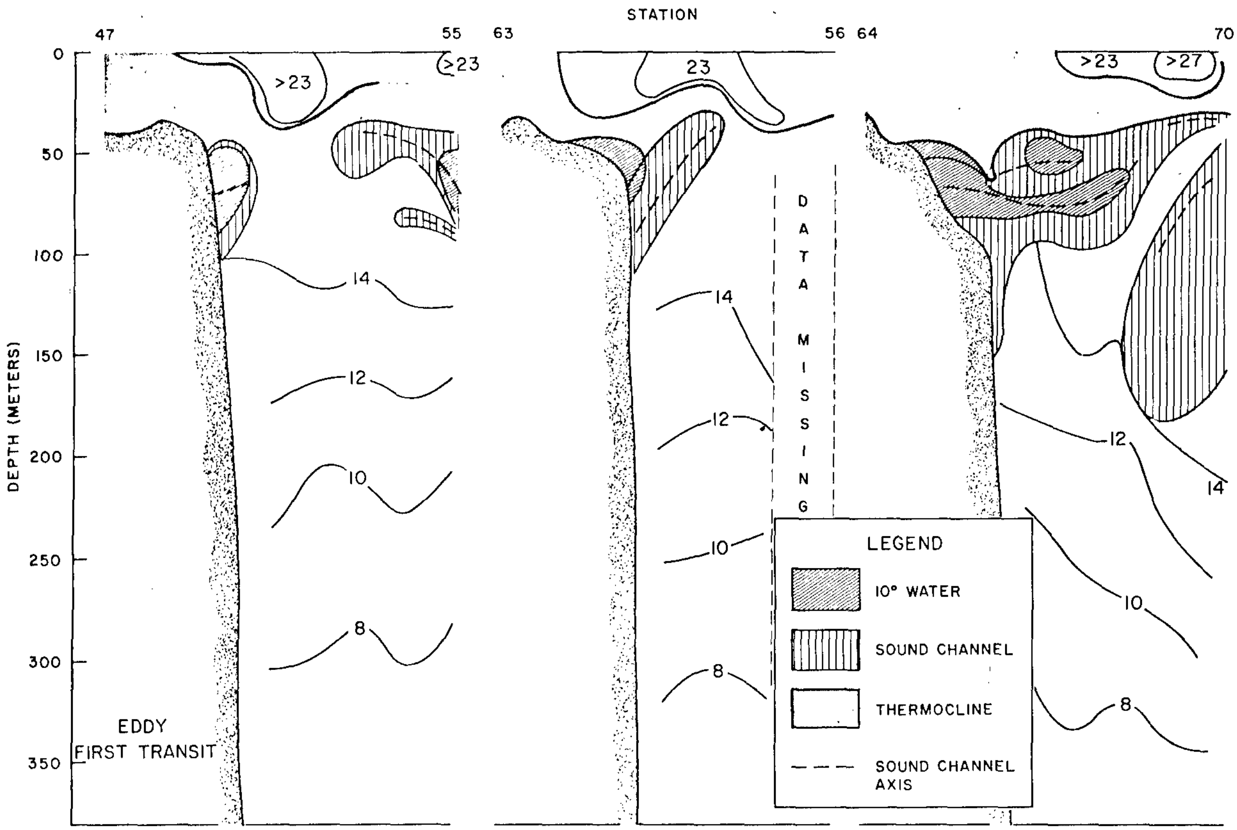

Figure 12 Temperature Sections 21-22 September 1967 (°C)

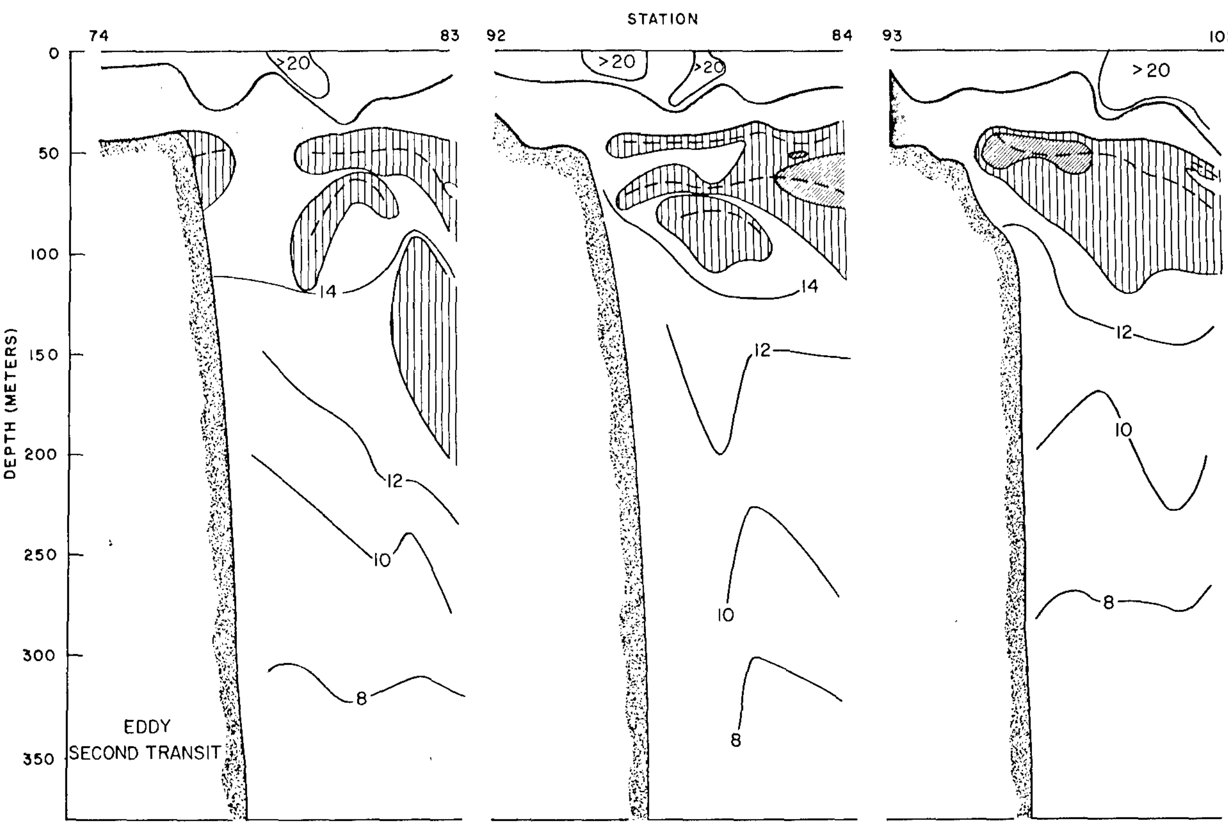

Figure 13 Temperature Sections 7 October 1967 (°C)

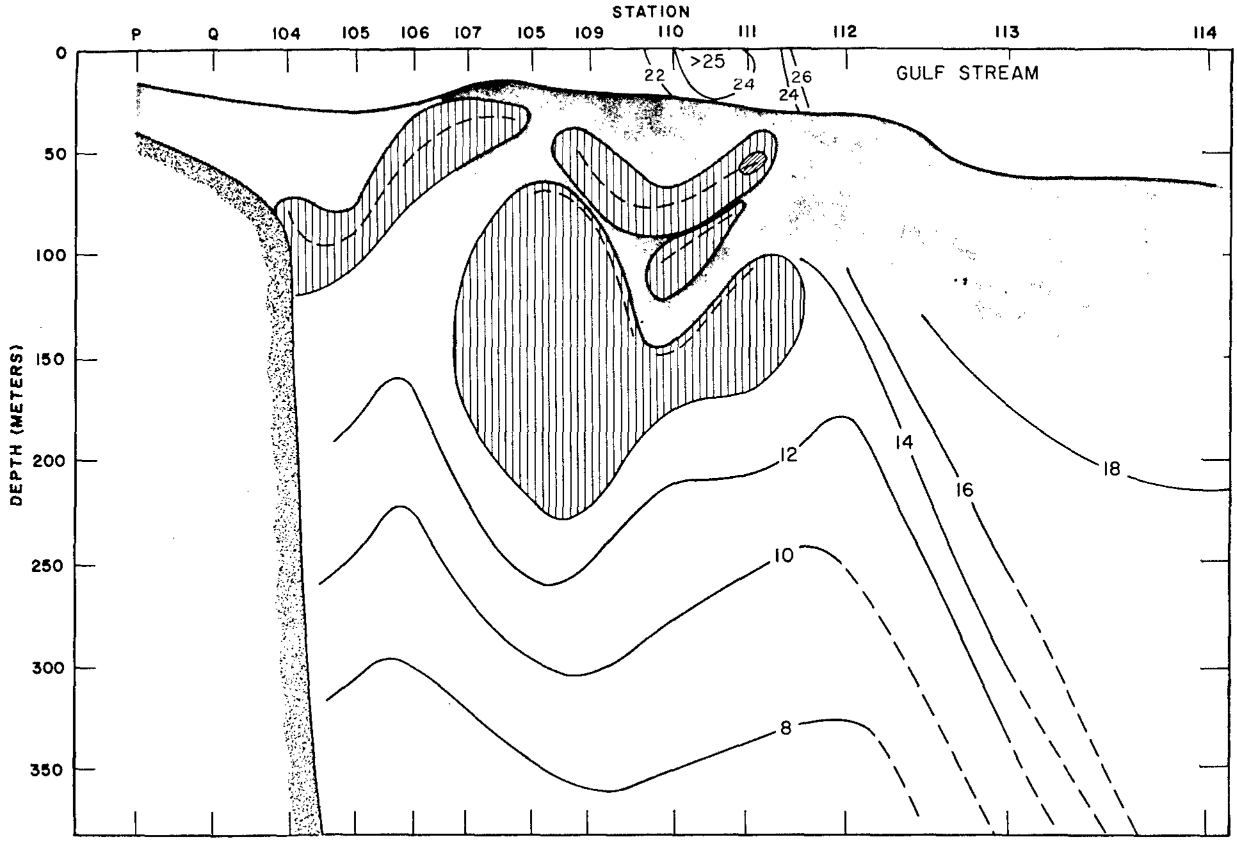

Figure 14 Temperature Section 7-8 October 1967 (°C)

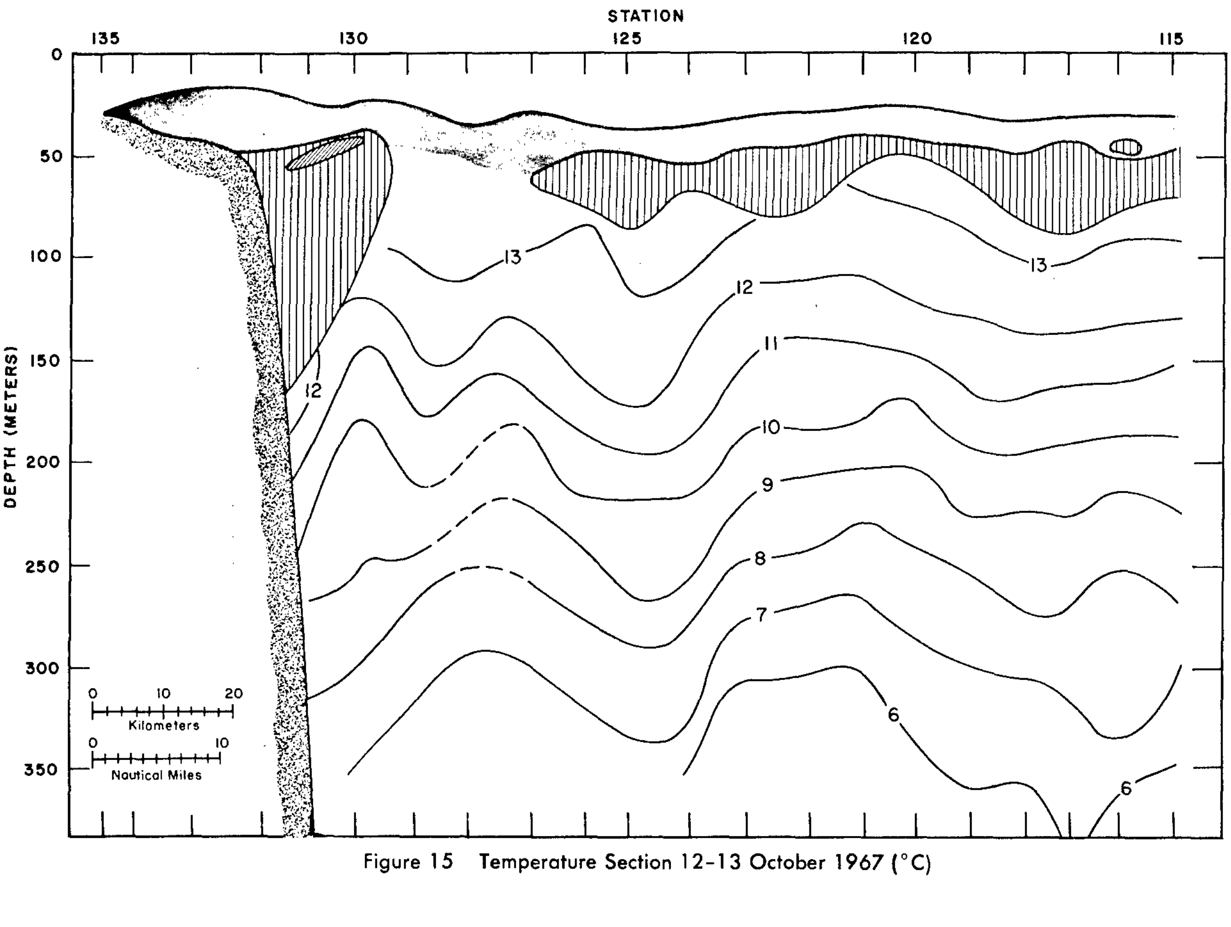

Figure 15 Temperature Section 12-13 October 1967 (°C)

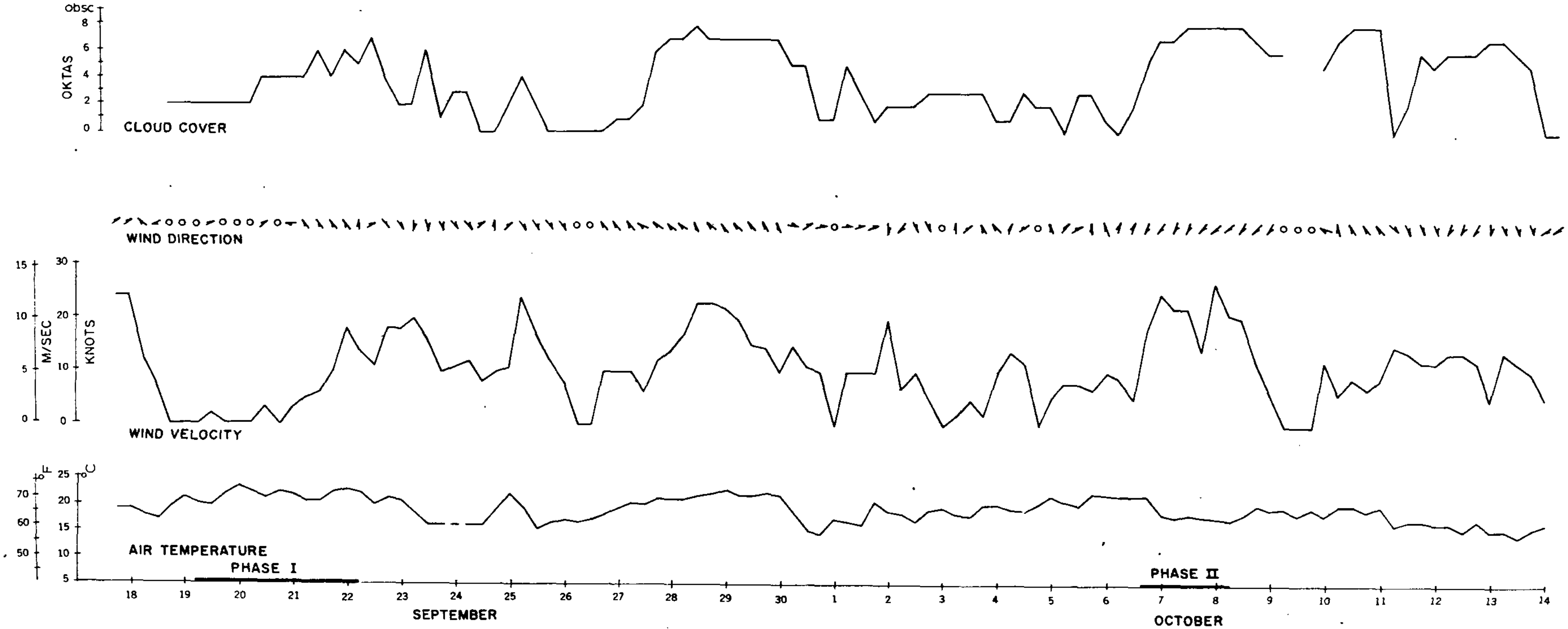

Figure 16 Meteorological Observations at Chesapeake Light Station

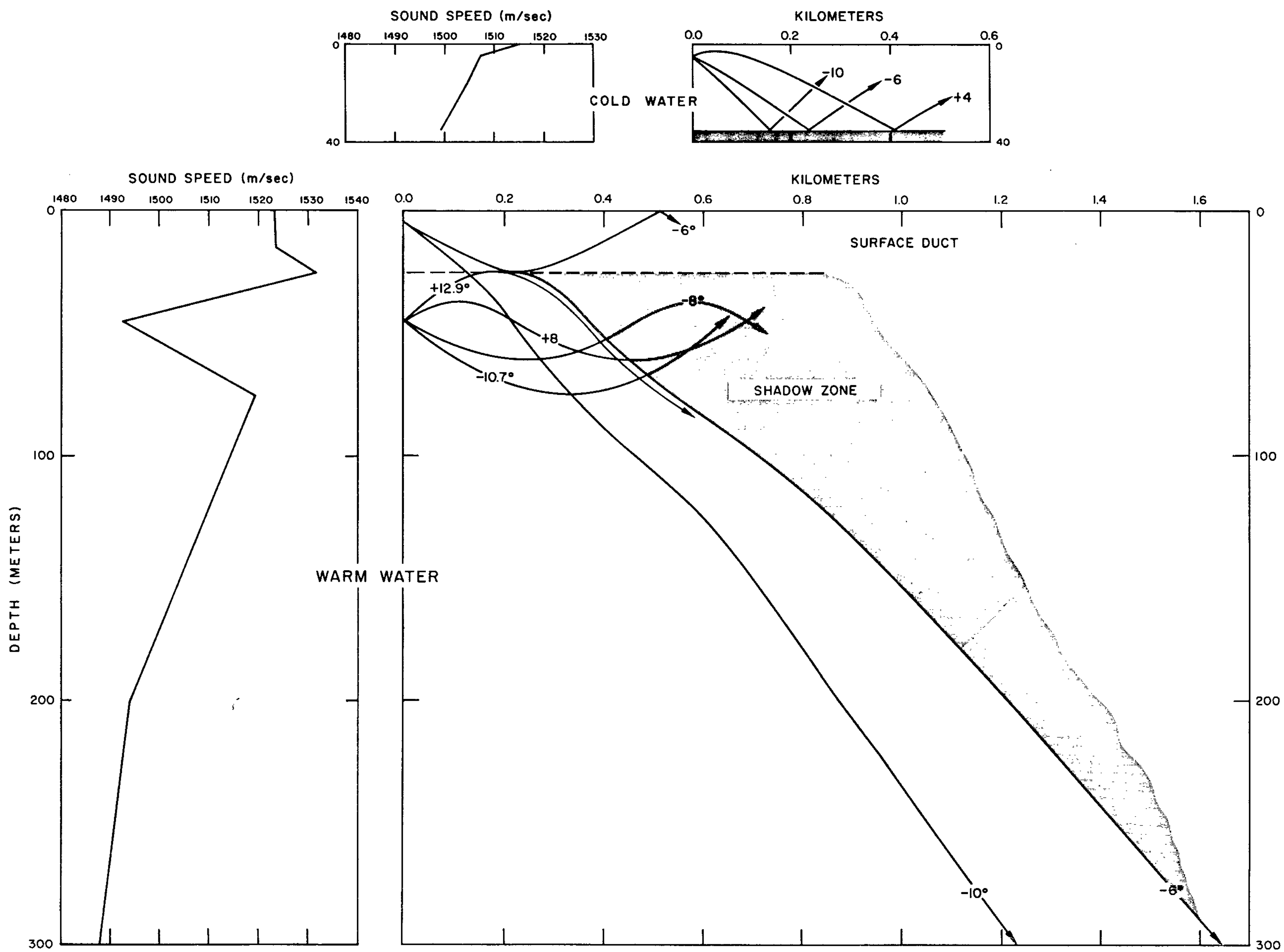

Figure 17 Ray Path Diagrams

U.S. Naval Oceanographic Office
ASWEPS SHALLOW WATER INVESTIGATION - VIRGINIA CAPES AREA, SEPTEMBER-OCTOBER 1967, by Alvan Fisher, Jr., February 1969. 25 p. including 2 tables and 17 figures. (TR-212) (ASWEPS Report No. 16)

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2. Thermohaline prediction
3. Shallow water

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ii. author: Alvan Fisher, Jr.
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13. ABSTRACT

Thermal structure of a rectangular area approximately 140 kilometers on a side contiguous to the Continental Shelf northeast of Cape Hatteras was investigated between 19 September and 13 October 1968. Major features included an area of warm (>21°C) surface water inshore of the northern wall of the Gulf Stream and a strong sound channel impinging upon the Continental Slope. A subsurface temperature maximum was observed beneath warm surface water at 70 percent of all deepwater stations. Zero layer depths occurred at 56 percent of relatively cold (<19°C) water stations over the Continental Shelf. These features persisted throughout the survey.

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EXPERIMENTAL DATA						
FORECASTING						
GULF STREAM						
OCEANOGRAPHIC DATA						
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SHALLOW WATER						
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